Simulation of a Tunisian Wind Farm of Sidi-Daoud Using PSAT

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Abstract-This paper deals with the analysis and simulation of a Tunisian Wind farms in Sidi-Daoud, the most important wind farm in Tunisia. In this farm constant speed wind turbines are used. The first section devoted to the presentation of the wind farm of Sidi-Doud. In the second part, we present the aerodynamic model of the wind turbine and the transient model of the induction generator used in this wind park. Finally, we simulate the electrical behavior of the wind farm under the turbulent wind upstream of each rotor turbine and identify the main features based on simulation software PSAT.

Keywords— Constant speed wind turbine, Transient model of induction machine; Power System software PSAT

Nomenclature

H_{wr} : The turbine inertia constant
H_m : The generator inertia constant
K_s : Shaft stiffness
D_{ls} : The mutual damping
D_{wr} : The turbine self-damping
D_m : The generator self-damping
T_{wr} : The aerodynamic torque
T_e : The electrical torque
w_{wr} : The rotational speed of the rotor
w_{ls} : Speed of the output shaft
w_m : The rotational speed of the generator
n_{gear} : Gearbox ratio
C_p : Power coefficient
P_{wr} : The aerodynamic power
T_{hs} : Torque on the high speed
T_{ls} : Torque on the low speed
R: Radius of the wind turbine rotor
v_w : Wind speed
v_t : The blade tip speed
λ : Tip speed ratio
ρ : Air density
r_s : Stator resistance
x_s : Stator leakage reactance
σ : Slip
x_m : Magnetization reactance
x_{R1} : Rotor leakage reactance
r_{R1} : Rotor reactance

I. INTRODUCTION

Wind energy is an energy source used for centuries old: it is a renewable energy source that saves fuel which contributes to the protection of the environment, non-polluting and economical. It is a source of inspiration for many manufacturers; they always push them to think new robust solutions, allowing maximum energy extraction and study of systems feasible.

Currently, Tunisia exploits its potential energy, including wind energy. The power and the availability of the wind are random and depend on the site and the period considered and Tunisia considers moderately windy [8], [4].

The STEG (Tunisian Society of Electricity and Gas) integrated the wind one among its choices in the objective to contribute to preserve the environment. It engaged of the feasibility studies for the exploitation of wind engage in the production of electricity, in cooperation with company MADE, carried out a first wind power station with Sidi-Daoud whose commissioning of the first slice took place in August 2000, [7].

In this paper, we present in the first section, the wind power farms of Sidi-Daoud and we describes the different models of the wind turbines constitute this park. In second section, we will perform simulations of part of this Wind farms. First of all, for the validation of the results, a software PSAT dedicated to the study of the Power Systems was introduced especially that this software is interested in the study of the wind systems. The last section of this paper present the simulation results of the wind farm under the turbulent wind upstream of each rotor turbine.

II. WIND ROSE OF THE WIND FARM OF SIDI-DAOUD

The wind rose is a spatial representation of the variation of the wind direction and average speed for such a Park. It illustrates the direction of the dominant winds on a site and allows planning the installation of turbines in order to minimize the effect of wake caused by the neighboring obstacles.

Fig.1 represents the wind roses of wind farm of Sidi-Daoud with 36 directions. We note the importance of the wind coming from the sectors West and South-east, and the existence non-negligible wind from the sector northwest. Furthermore, the wind was calm persists both sectors Southeast and South [2].

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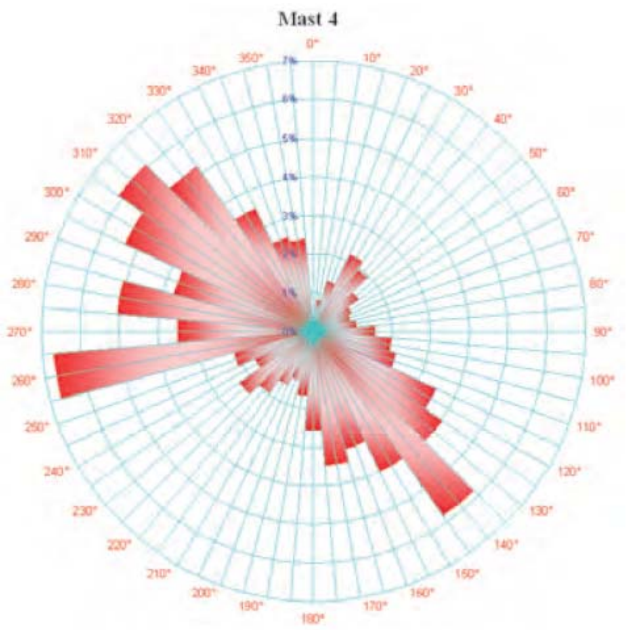

Fig. 1.Wind Rose in the region of Sidi-Daoud [6]

Figure 2 presents the frequency of wind speeds at the park since the 01/01/2010 until 31/12/2010 the measured values represents the average value of the wind speed for hour.

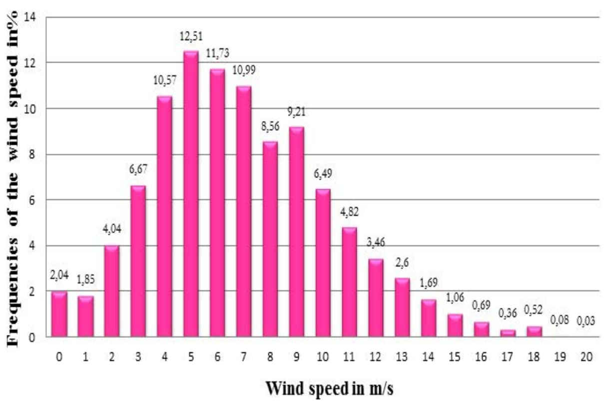

Fig 2. Frequency of wind speeds from 1/01/2010 to 31/12/2010 in the wind farm of SidiDaoud [14].

III. Presentation Of The Wind Power Farm Of Sidi-Daoud

The total surface used for the establishment of the power plant is about 9 ha and extends on 3.5 km from the coast shown in Fig.3 It is about a site sufficiently been windy, capable to receive and close to the grid, [5].

Wind turbines of the first and second section are established on the summits of the two mountains "Djebel El Hammam" and "Jebel Ghormane" whose altitude is respectively 50 and 100 m above the sea level. The wind turbines of the third section are located at the bottom of these two hills and approximately one hundred meters of marine coasts [2]. Figure 3 shows the topographic profile and the location of wind turbines on site.

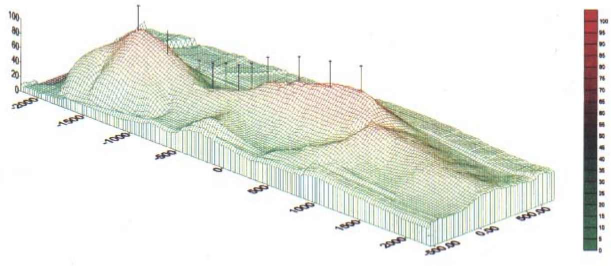

Fig. 3.SidiDaoud site relief [2]

IV. Different Models Of Wind Turbines Constitute The Central Of Sidi-Daoud

The wind farm of Sidi-Daoud consists of four models of aero-generator with the horizontal axis, all from the same manufacturer Spanish MADE. The first model was installed is the AE32 in 2000 with a power of 330kW, using an asynchronous squirrel-cage generator and a system of aerodynamic unhooking “stall” with a fixed pitch angle of the blades. The site comprises 32 aero-generators of this model “phase A”.

A first extension of the site in 2004 is then accomplished with the implantation of 12 wind turbines "Phase B" with 3 different models, 10 AE46 whose power of each one is of 660 kW using same technology as its predecessor, the AE52 with a power of 800kW using a synchronous generator, with a variable pitch angle of blade and finally the AE61 whose power is of 1320 kW and using the same technology as the AE32 and the AE46.

Following the good wind potential of the site and to the infrastructure already exists, a second extension "phase C" was to realize in 2009 comprising 26 AE61 generator, we summarizes the three stages of wind farm of Sidi-Doud in a TABLE I.

TABLE I. TABLESTEPS SIDI DAOUD WIND FARM [8], [2]

designations	Step A	first extension	second extension
Number of turbines	32	12	26
installed power (Mw)	10.56	8.72	34.32
Industrial commissioning	August 2000	September 2003	June 2009
constructor	MADA Spain	MADA Spain	MADA Spain
annual production (GWh)	28	20	100

The STEG is provided the characteristic of the power at the level of the turbine according of the wind speed for each aero-generator of the central Sidi-Daoud. This characteristic illustrated by Fig.4. The machines start from the same speed of 3 m / s (except AE-32, which starts at 4 m / s) this speed is boot

speed from which the turbines begin to produce and must stop at maximum speed 25 m / s.

This power reaches its nominal value for a nominal wind speed of about (13, 15, 12 and 17 m / s). Beyond the nominal speed, the power supplied by the synchronous machine AE-52 remains constant, on the other hand, that provided by asynchronous machines AE-32, AE-46 and AE-61 decreases slightly with the wind speed [2].

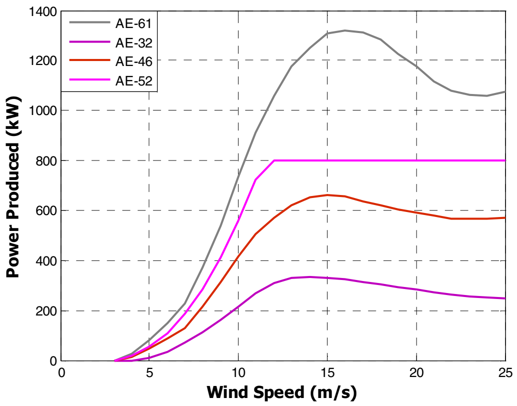

Fig. 4. Power curves of wind turbines

V. Wind Turbine Modeling

A. Aerodynamic model:

The mechanical P_w power available on the shaft of a wind turbine v_w of a captured any wind speed is determined analytically by the following formula:

$$P_w = \frac{1}{2}\rho C_p(\lambda) A_r v_w^3 \tag{1}$$

With A_r is the area swept by the wind turbine (m^2) and ρ is the density of air ($kg.m^{-3}$), whose value depends on the height at which is installed the turbine and the power coefficient C_p depends on the speed ratio which is defined as follows:

$$C_p = 0.44(\frac{100}{\lambda_i} - 5.4)e^{-\frac{13.5}{\lambda_i}} \tag{2}$$

With: $$\lambda_i = \frac{1}{\frac{1}{\lambda} + 0.002} \tag{3}$$

The speed tip ratio λ is the ratio between the blade tip speed v_t and the wind upstream the rotor v_w :

$$\lambda = \frac{v_t}{v_w} = \eta_{GB}\frac{2Rw_{wr}}{pv_w} \tag{4}$$

B. Transmission System Model

We can model the driving device of the chain conversion of wind turbine by a mechanical model approximate with two mass shown in fig.5[3],[1].

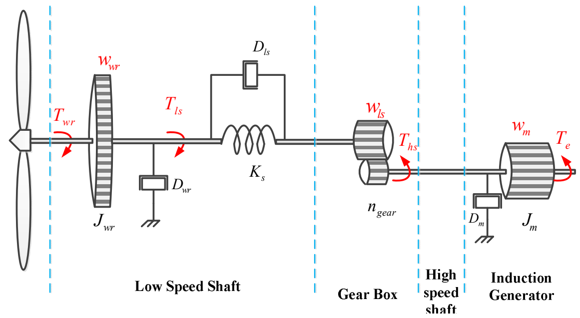

Fig. 5. Schema of the transmission system with two masses [3]

The differential equations of the mechanical part by a model of a two-mass drive train model obtained by neglecting the coefficients of external frictions of the rotor and generator are given by:

$$\begin{cases} \frac{dw_{wr}}{dt} = \frac{(T_{wr} - K_s\gamma)}{2H_{wr}} \\ \frac{dw_m}{dt} = \frac{(K_s\gamma - T_m)}{2H_m} \\ \dot{\gamma} = \Omega_b(w_{wr} - w_m) \end{cases} \tag{4}$$

With T_{wr} is the mechanical torque defined by:

$$T_{wr} = \frac{P_w}{w_{wr}} \tag{5}$$

C. Induction Generator Model

The simplified electrical circuit used for the induction generator with squirrel cage is the same as that for the induction motor with single cage, shown in Fig.6. The only difference is that the currents are positive when injected into the network [10].

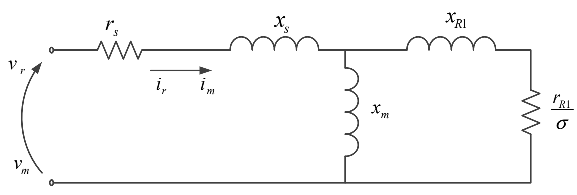

Fig. 6. Order III induction motor: electrical circuit [10].

The equations are formulated in terms of the real (r) and imaginary (m) axis, with respect to the network reference angle. In a synchronously rotating reference frame, the link between the network and the stator machine voltages is as follows:

$$v_r = V\sin(-\theta)$$
$$v_m = V\cos(\theta) \qquad (6)$$

And the power absorptions are:

$$P = v_r i_r + v_m i_m$$
$$Q = v_m i_r - v_r i_m + b_c\left(v_r^2 + v_m^2\right) \qquad (7)$$

Where b_c is the fixed capacitor conductance which is determined at the initialization step. The differential equations in terms of the voltage behind the stator.

The link between voltages, currents and state variables is as follows:

$$e_r^{'} - v_r = r_s i_r - x^{'} i_m$$
$$e_m^{'} - v_m = r_s i_m + x^{'} i_r \qquad (8)$$

and: $v_r = -r_s i_r + x^{'} i_m + e_r^{'}$ (9)

Where $e_r^{'}$ is the real part of transient voltage, $e_m^{'}$ is the transient voltage on imaginary axis and $x^{'}$ is transient reactance.

$$\begin{cases} \dot{e}_r^{'} = \Omega_b\left(1-w_m\right)e_m^{'} - \dfrac{e_r^{'} - \left(x_0 - x^{'}\right)i_m}{T_0^{'}} \\ \dot{e}_m^{'} = -\Omega_b\left(1-w_m\right)e_r^{'} - \dfrac{e_m^{'} - \left(x_0 - x^{'}\right)i_r}{T_0^{'}} \end{cases} \qquad (10)$$

Where x_0, $x^{'}$ and $T_0^{'}$ can be obtained from the generator parameters:

$$\begin{cases} x_0 = x_s + x_m \\ x^{'} = x_s + \dfrac{x_{R1}x_m}{x_{R1}+x_m} \\ T_0^{'} = \dfrac{x_{R1}+x_m}{\Omega_b r_{R1}} \end{cases} \qquad (11)$$

Where the electrical torque T_e is:

$$T_e = e_r^{'} i_r + e_m^{'} i_m \qquad (12)$$

VI. PV GENERATOR

PV generators fix the voltage magnitude and the power injected at the buses where they are connected, as follows [10]:

$$P = -P_g$$
$$V = V_0 \qquad (13)$$

VII. WIND MODELS

On PSAT the wind is modeled by a block window allows to easily analyze and modify all the parameters related to the behavior of the wind as the wind model type as the Weibull distribution or the composite model which includes average speed , the intensity of wind gusts and turbulence level or by real measures of the wind speed [3].

In our case we chose the method most frequently used to describe the wind speed which is the Weibull distribution.

The variations in wind speed a function of time $v_w(t)$ are obtained by distributing wind by the equation (3.1).

$$v_w(t) = \left(-\frac{\ln\ \tau(\mathrm{t})}{\mathrm{c}}\right)^{\frac{1}{k}} \qquad (14)$$

Where $\tau(\mathrm{t})$ a generator of random numbers, C is the scale factor of the Weibull distribution and K is the shape factor. Then, the wind speed is calculated, in framing the initial average value of the wind speed V_{wa} as follows [10]:

$$\breve{v}_w(t) = \left(1 + v_w(t) - \hat{v}_w\right)v_{wa} \qquad (15)$$

Where $\hat{v}_w$ is the mean value of $v_w(t)$.

VIII. SIMULATION OF PHASE C OF THE SIDI DAOUD WIND FRAM

The phase C of Sidi-Daoud wind farm consists of 26 aero-generators AE61 spread over 3 lines, the first line designated" 1C" contains 9 aero-generators located about 1.56 km from the substation, the second line contains 10 aero-generators located about 2.765 km from the post of transformation and the third line is located at 0.77 km from the post of transformation and contains 7 aero-generators. In Sidi-Daoud wind farm, converting electricity produced in two stages, the first of 690 V to 30 kV by a transformer of the each turbine, and the second from 30 kV to 90 kV by the external post after passage of the MT voltage underground cable from the foot of the tower to the MT / HT [11]. We visualize the wind turbines in real operating and identify the main features. The simulated structure is shown in fig.7.Parameters of the aero-generator constituents AE-61 are recapitulated in Table II.

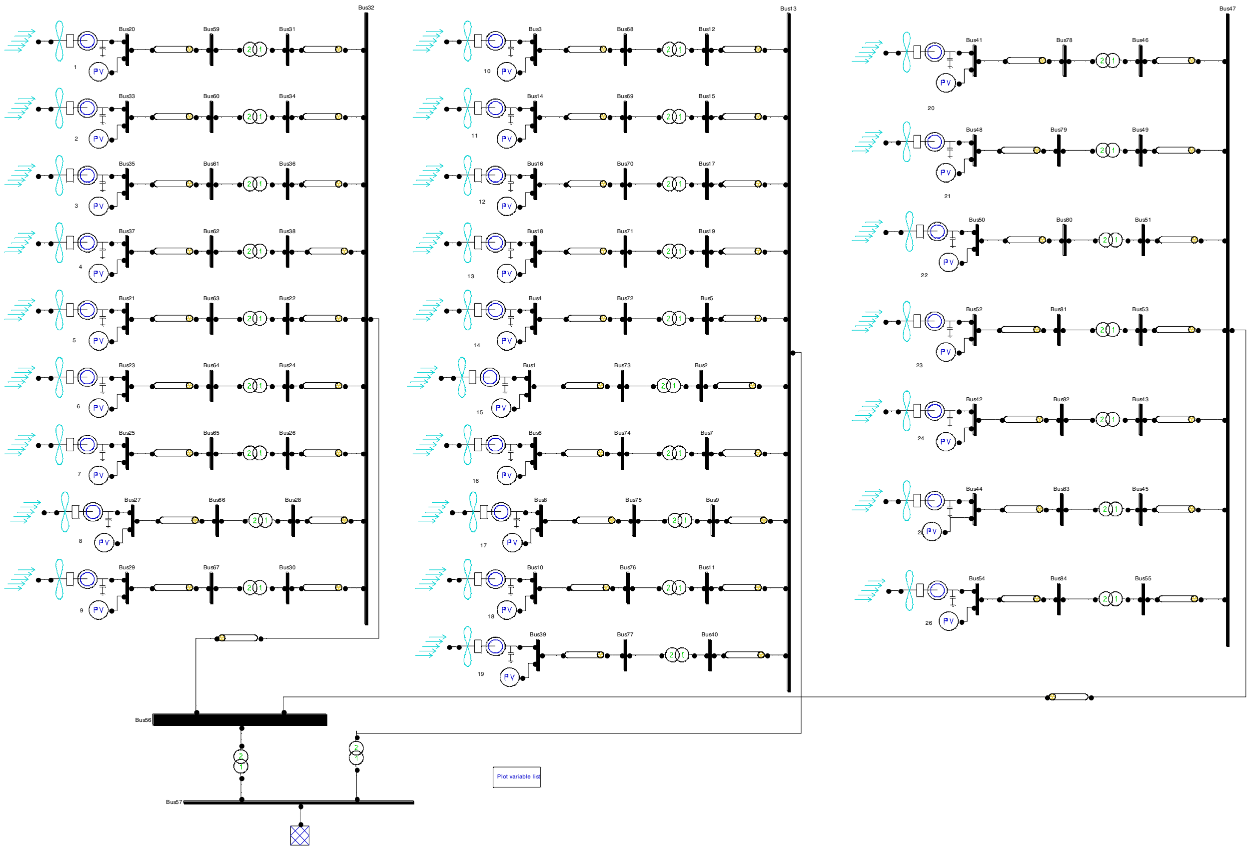

Fig. 7. Phase C of the Wind Farm of Sidi Daoued

TABLE II. PARAMETERS OF THE WIND TURBINE COMPONENTS

parameters	values
r_{R1}	0.0108 pu
x_{R1}	0.1284 pu
r_s	0.0097 pu
x_s	0.1284 pu
x_m	5.579 pu
H_m	3.7146 s
H_{wr}	5s
K_s	70 pu
Transformer resistance	0.0065pu
Transformer reactance	0.0356
Line resistance BT	0.272 Ω/Km
Line reactance BT	0.08/100π H/Km
Line resistance HT	0.159 Ω/Km
Line reactance HT	0.138 /100π H/Km

PSAT we provided in the first time, after resolution of the equations powers a static report that contains the results of the various state variables of the system, this part is a step to initialize the wind turbines. Generators PV are necessary to impose the desired voltage and active power on the bus of wind turbines. We extracted the static results of active and reactive power in the bus of each machine. These results are summarized in the following Table III:

TABLE III. THE RESULTS OF ACTIVE AND REACTIVE POWER IN THE PERMANENT RÉGIME FOR PHASE C

N° AG	Wind speed (m/s)	Power active (pu)	Reactive power (pu)
1	7.1	0.2171	-0.06859
2	7.8	0.2855	-0.14931
3	6.8	0.1898	-0.03664
4	8.5	0.3587	-0.2329
5	7.5	0.2555	-0.11519
6	5.7	0.1032	0.06742
7	6.6	0.1724	-0.01706
8	6.4	0.1557	0.00275
9	4.3	0.02995	0.15743
10	5.7	0.1101	0.04671
11	4.8	0.05102	0.11935
12	7	0.2079	-0.0719
13	5	0.06105	0.10624
14	6.5	0.164	-0.02004
15	7.2	0.2265	0.09331
16	5.6	0.09653	-0.06136
17	5.9	0.1172	0.03566
18	5.1	0.0664	0.09785
19	5.5	0.09007	0.06821
20	5.5	0.09007	0.08589
21	7	0.2079	-0.05709
22	6.2	0.1397	0.02463
23	7.7	0.2754	-0.13726
24	6	0.1245	0.04256
25	6.5	0.164	-0.00566
26	7.7	0.2754	-0.13819

Follows, PSAT can also perform the simulation in the time domain in order to study the behavior of the dynamic system. These simulations are based on numerical integration of differential algebraic equations (DAE) that describe the dynamic function of the system in our case they are used to study the effect of variation of wind speed on all variables.

The 26 wind turbines of Sidi-Daoud farm are simulated for turbulent wind speed with a scale factor of the Weibull distribution c = 2 and a shape factor k = 9. Figure 8 shows the variation of the wind speed for wind turbine number 1. We note that the wind speed oscillates around its average value 7.1 m / s.

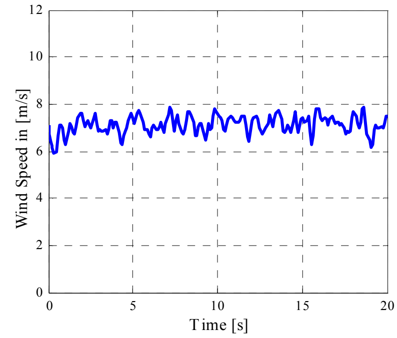

Fig. 8. Wind speed

Figures from 8 to 15 shows that the behaviors of all variables are random and oscillates around its operating values, it helps to explain that these variables vary due to the variation of wind speed.

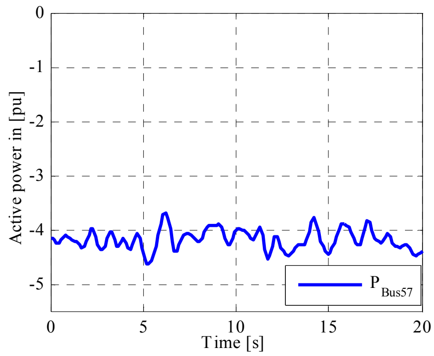

Fig. 9. Active power in the bus network

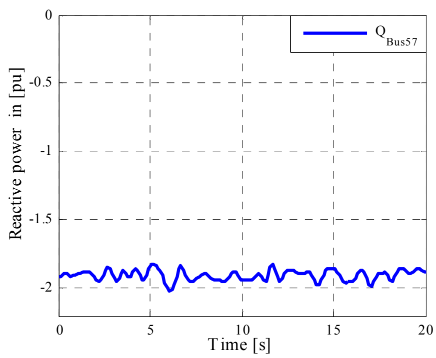

Fig. 10. Reactive power supplied by the network

Figure 8 and Fig.9 shows respectively the active power and reactive power in the bus which is connected to the network. Gaits powers are random and fluctuate around its average values. We note that the network received total power of 4.2 pu is equivalent to a production of 6.5 MW and total reactive power supplied around 1.9 pu which is also equal to 2.9 MVAR, which gives a power factor equal to 0.91.

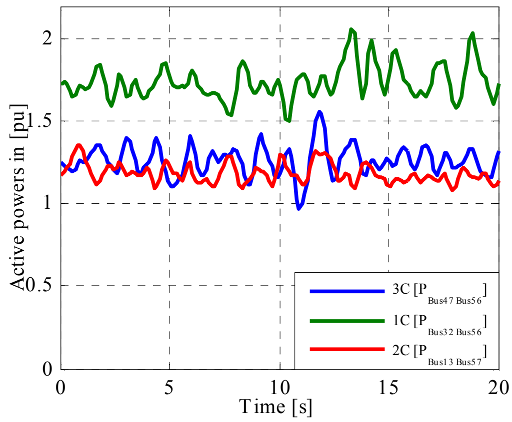

Fig. 10. Active power in the 3 lines 1C, 2C and 3C

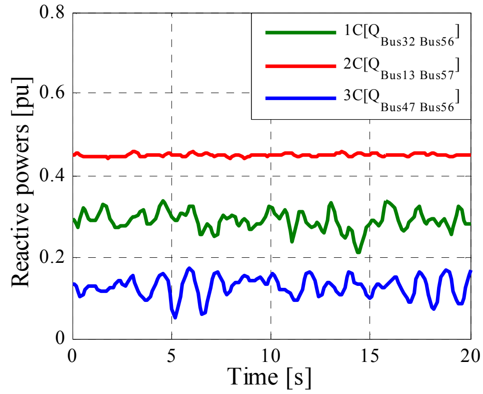

Fig. 11. Reactive power in 3 line 1C, 2C and 3C

Figure 10 and Fig.11 illustrate respectively the active and reactive power in different lines 1C, 2C and 3C. Three lines produce successively 1.7, 1.17and 1.25pu active powers of the network and received respectively 0.29, 0.45 and 0.13 of reactive power.

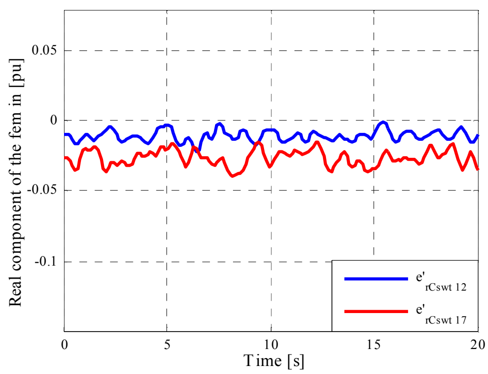

Fig. 12. Real component of the fem for two different values of wind speed

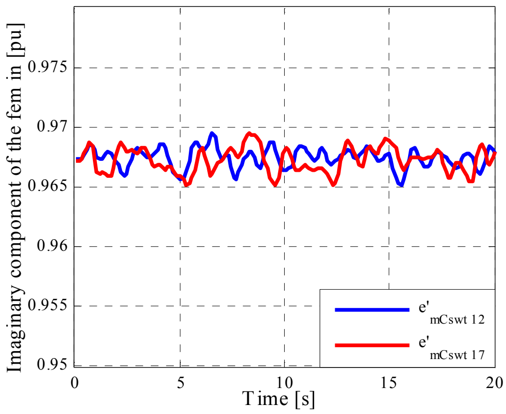

Fig. 13. Imaginaire component of the fem for two different values of wind speed

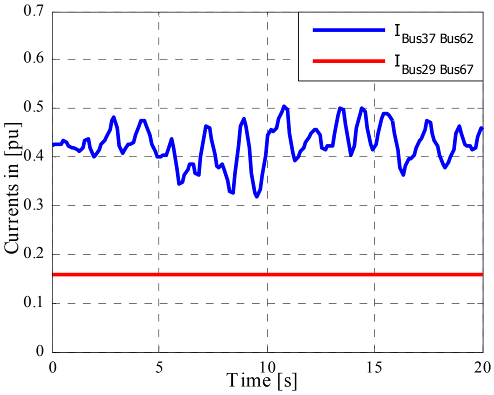

Fig. 14: currents for two different values of wind speed

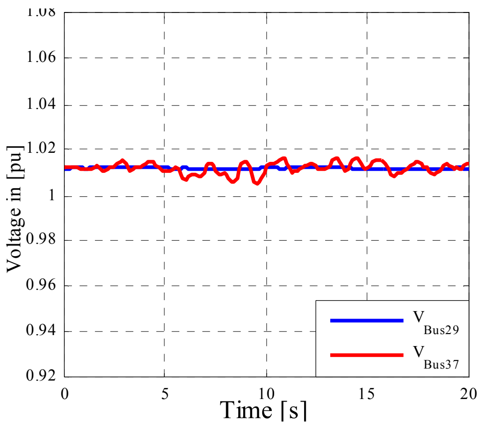

Fig. 15. power of the machine for different values of the two wind speed

We shows the real and imaginary component of the fem of the machine for two values of wind speed 8.5 m / s and 4.3 m / s Fig.12 and Fig.13. We notice that the magnitude of the transient f.e.m increases when wind speed increases, also for currents and voltages in the bus machines Fig. 14 and Fig. 15. We conclude that the variation of the wind speed value affected the production of Wind Energy.

VX. Conclusion

This paper presents the simulation of phase C of Sidi-Daoud wind farm composed by 26 wind turbines at constant speed using such AE61gerator directly connected to the electric grid. The simulation aims to better understand the dynamic behavior and the electrical properties of the constant speed wind turbine. In this work, we demonstrate that the electrical grid is affected by the turbulent wind speed variations it can degrade the quality of power and has a detrimental effect on the installation. The greatest handicap of the constant speed wind turbine technology studied (AE61) is that it does not offer the possibility of the power control under wind speed variation.

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